Resonant Half Bridge LLC Controller enhance slim Digital TV design

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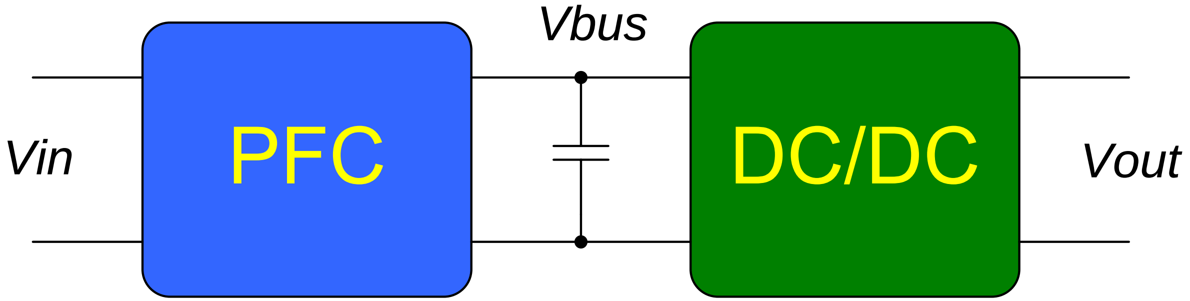
Outline

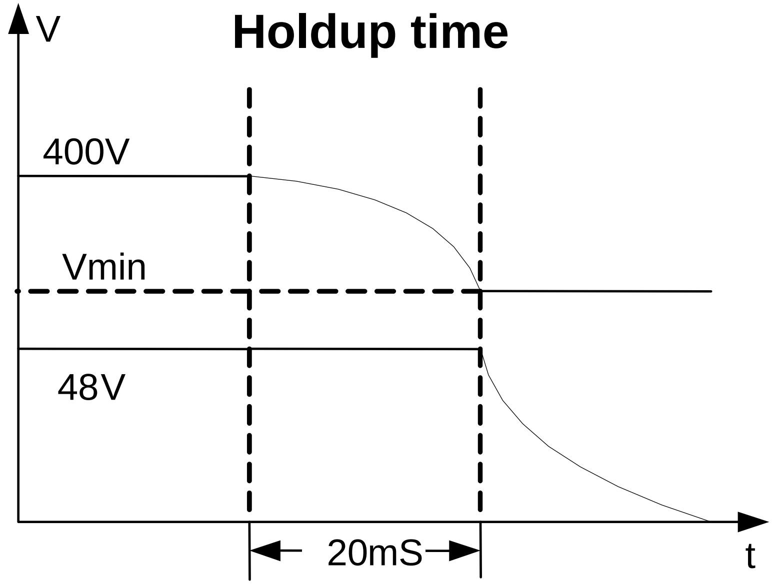
- Introduction to LLC resonant converter
- Step by step design method
- Other design issues for LLC resonant converter
- TI 8 pin LLC controller introduction
- Application example –300W slim digital TV power solution

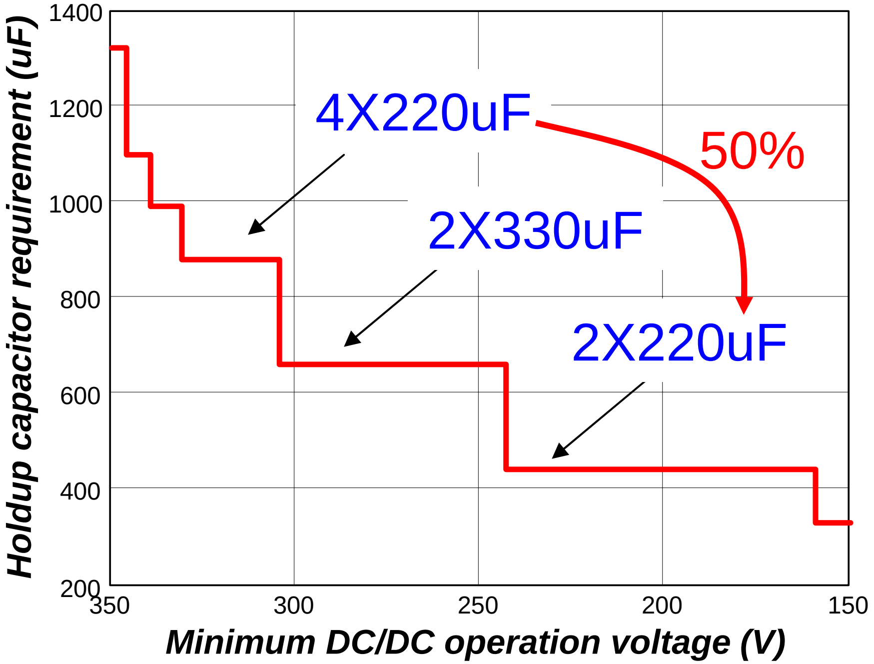
Design Challenges for DC/DC

- Higher power density
  - Higher efficiency, smaller heat sink
  - Higher switching frequency, smaller magnetics
  - Less energy storage capacitors, smaller size
- Holdup time requirement
  - Large energy storage capacitor
    - Higher cost
    - Large size

Holdup Time Requirement

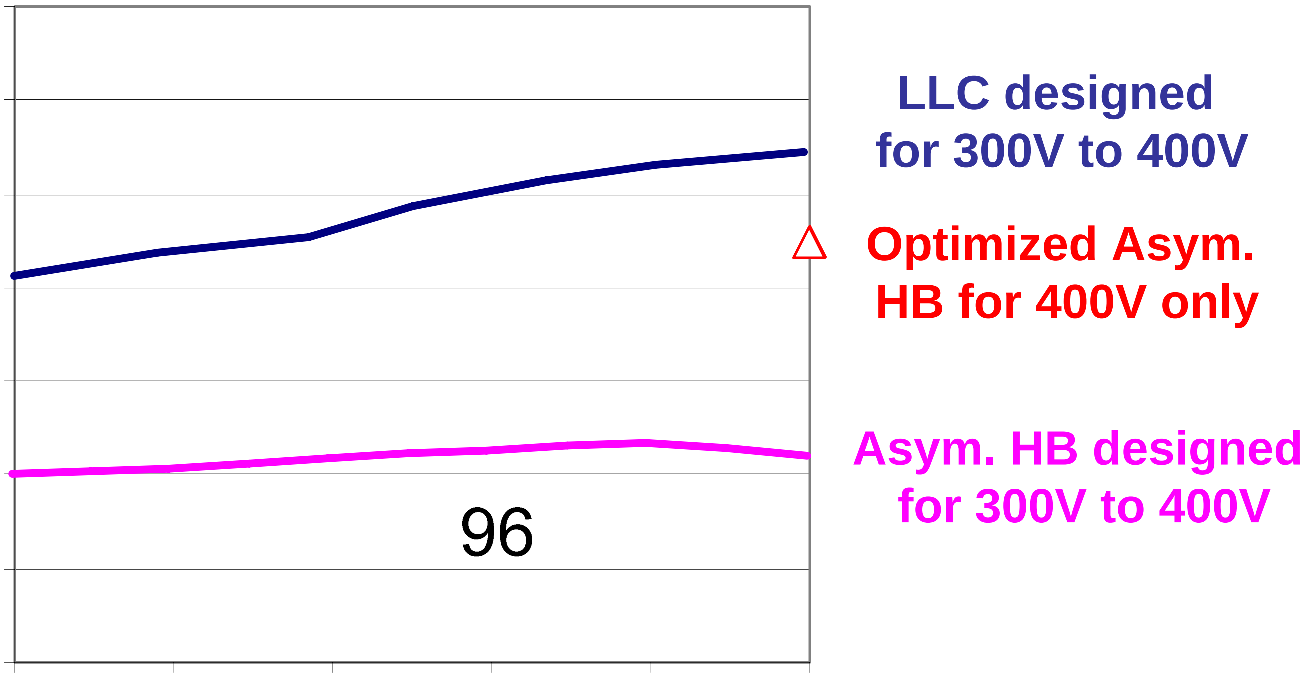






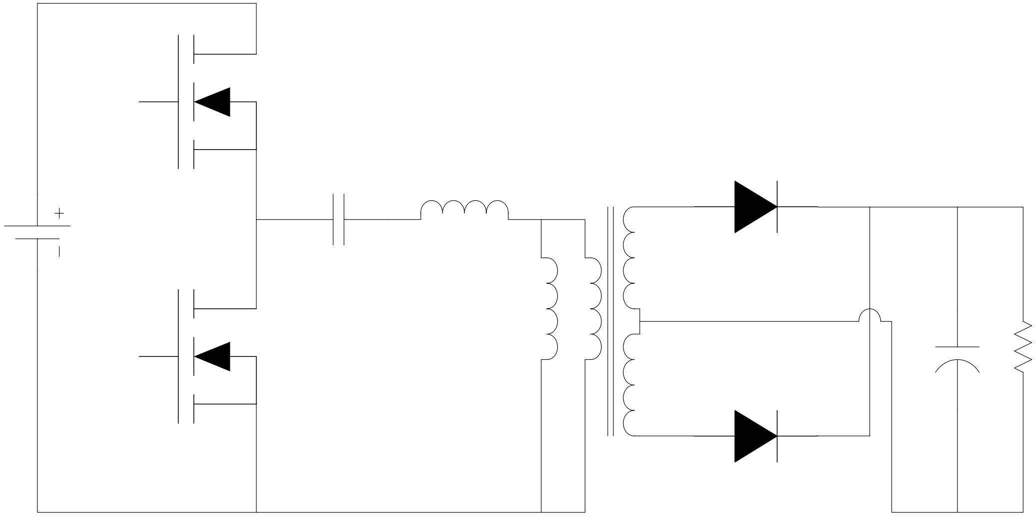
- ➢ Large capacitor required to provide energy during holdup time
- ➢ Wide operation range DC/DC can reduce holdup cap requirement

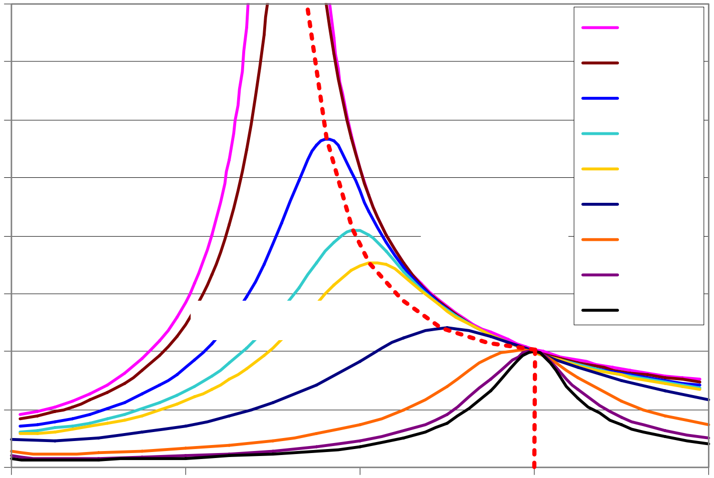
PWM Converter with Wide Operation Range



- Low Efficiency at normal condition due to wide operation range
- LLC resonant converter can achieve higher efficiency

LLC Resonant Converter with Wide Operation Range





Resonant frequency

$$f_0 = \frac{1}{2\pi\sqrt{L_r C_r}}$$

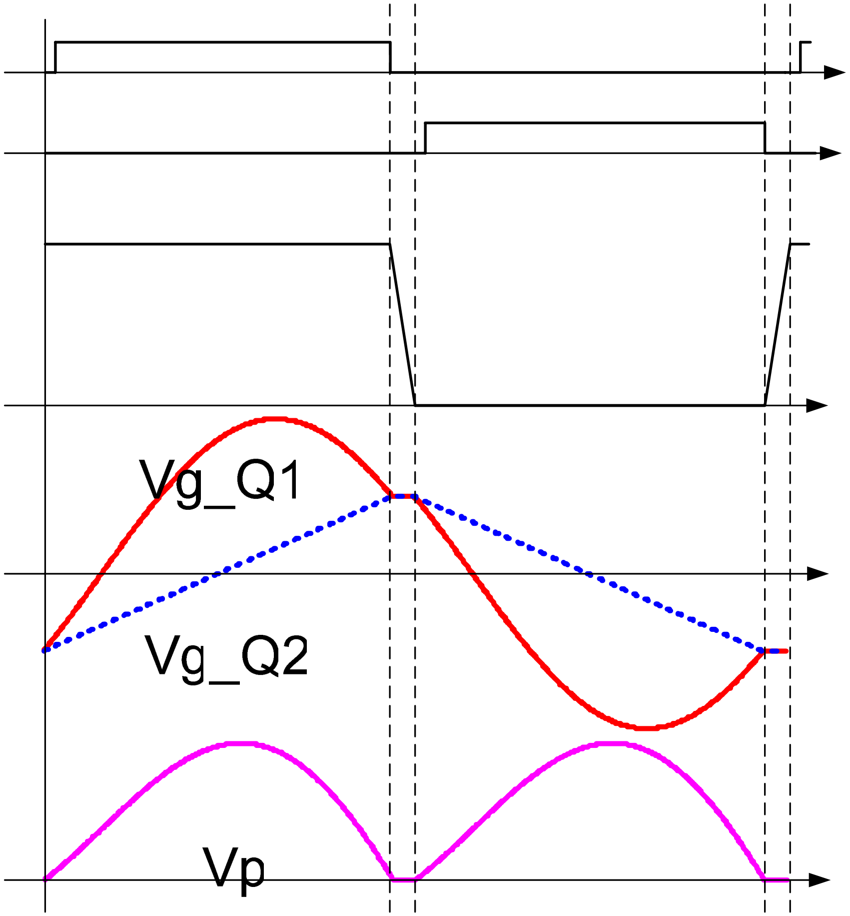
Transformer turns-ratio

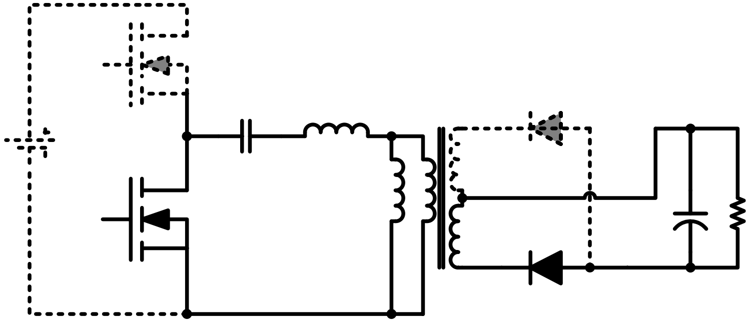
$$n = \frac{V_{in}/2}{V_o}$$

- ➢At 400V input, switching frequency is resonant frequency
- ➢During holdup time, switching frequency is reduced

Operation Principles

At Resonant Frequency

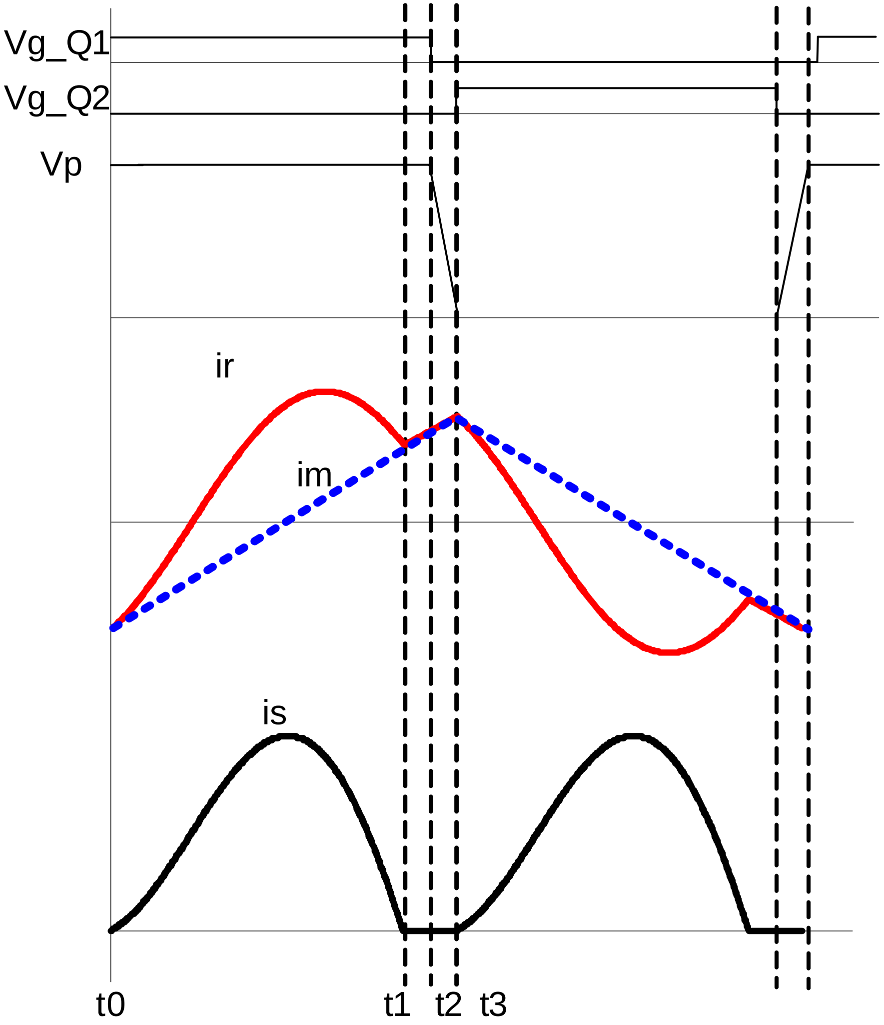


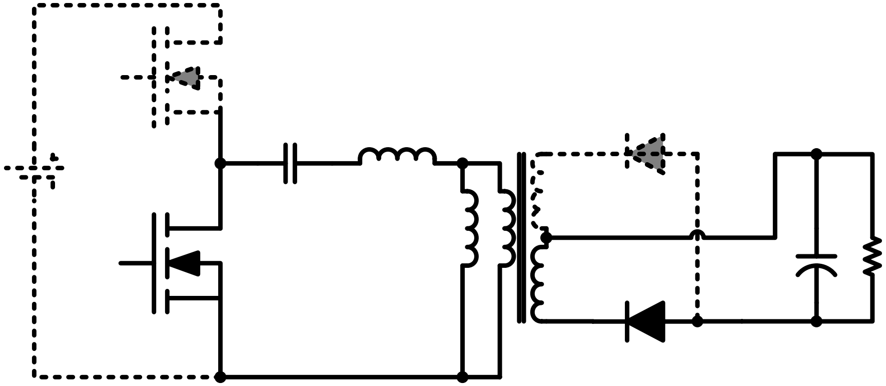


- At resonant frequency, maximum efficiency is expected

Operation Principle

Below Resonant Frequency

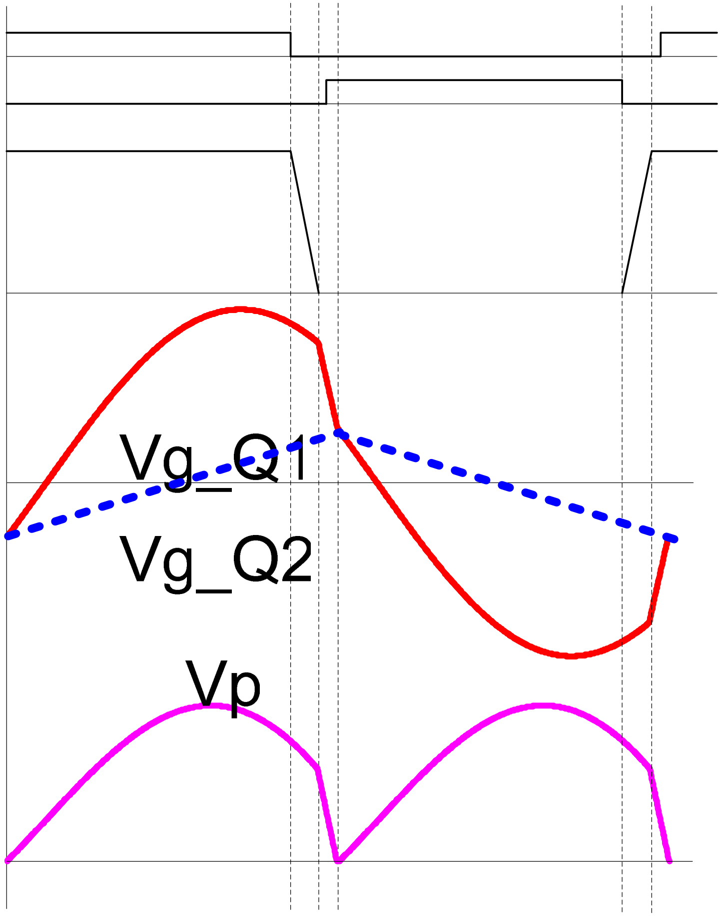


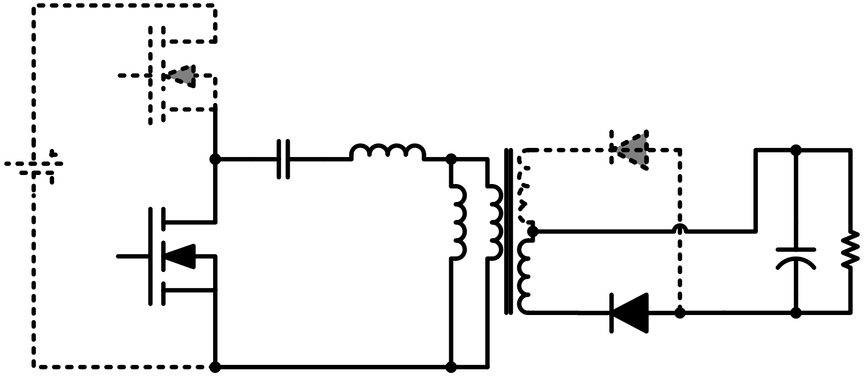


- When switching frequency is below resonant frequency, magnetizing inductor begins to participate in resonant and increase voltage gain
- Secondary diode becomes discontinuous

Operation Principle

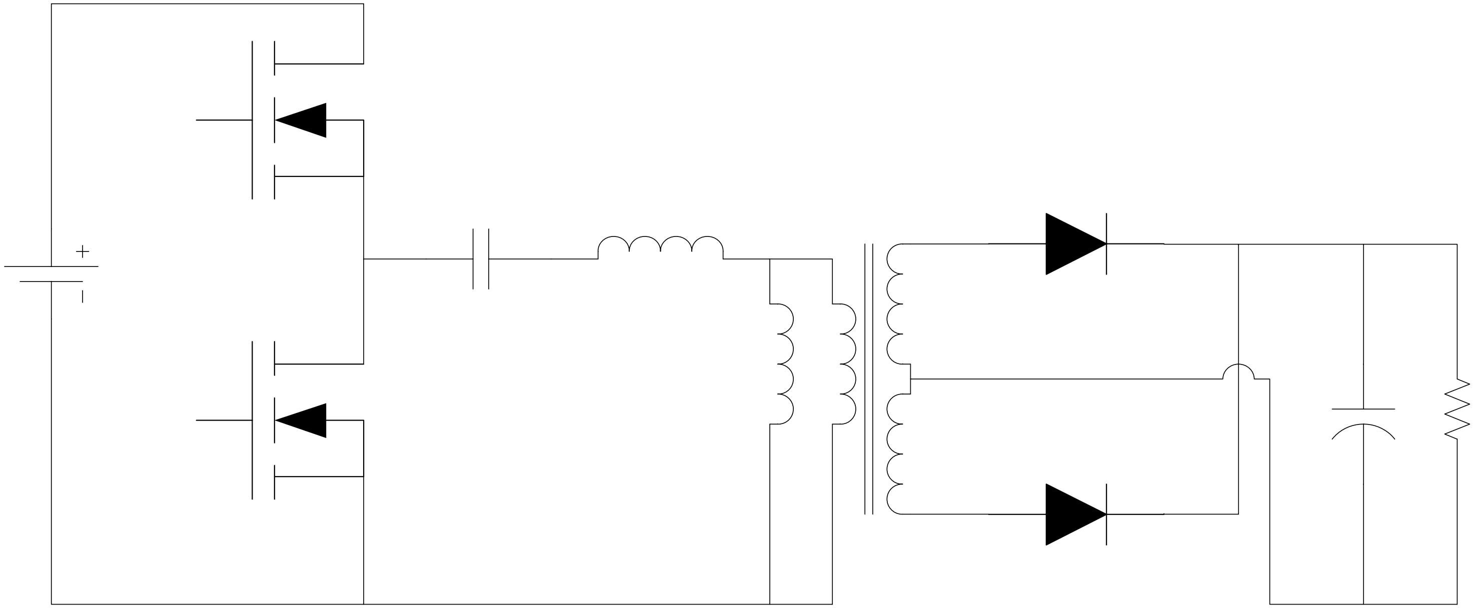
Above Resonant Frequency





- ➢When switching frequency is above resonant frequency, circuit behaves as SRC
- ➢Secondary current becomes CCM, reverse recovery loss increases

Benefits of LLC Resonant Converter



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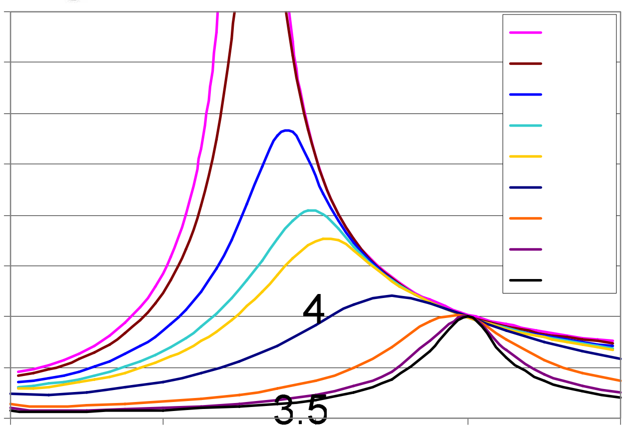
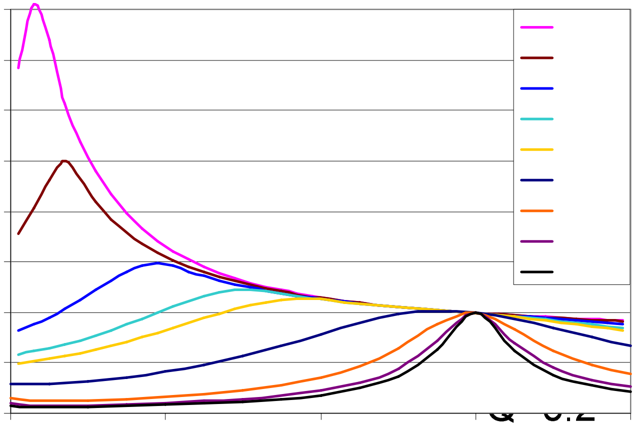
- ZVS can be achieved by utilizing transformer magnetizing inductor
- Capacitor filter, less voltage stress on rectifiers
- Smaller switching loss due to small turn off current
- Variable switching frequency control, not sensitive to load change
- Wide operation range without reducing normal operation efficiency

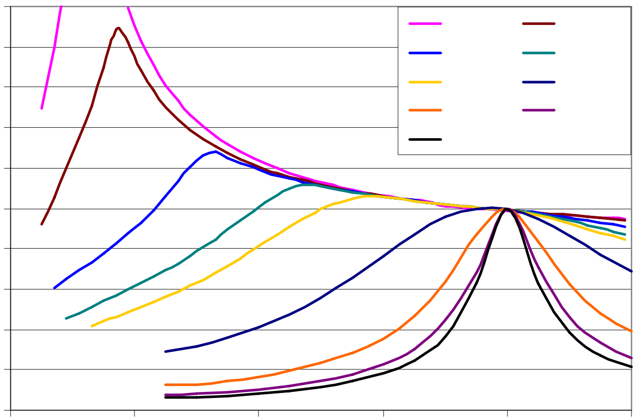
Impacts of Circuit Parameters



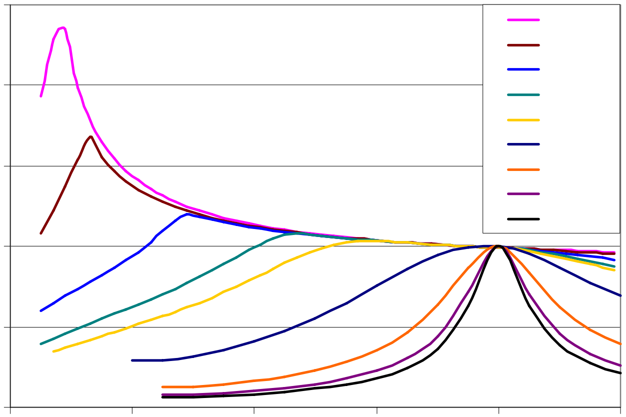
$L_n = 1$



$L_n = 5$

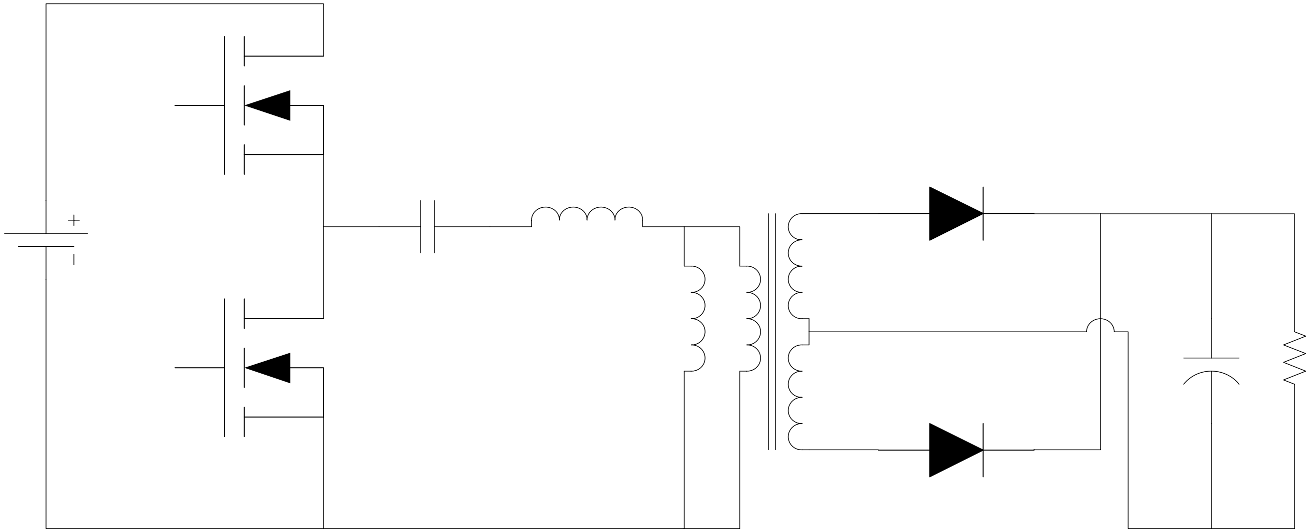


$L_n = 10$



$L_n = 15$

Design Goals for LLC Resonant Converter



Inductor Ratio

$$L_n = \frac{L_m}{L_r}$$

Quality factor

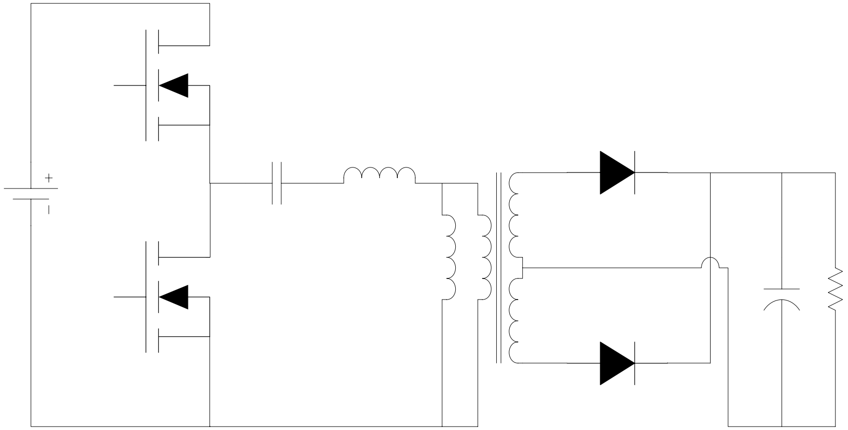
$$Q = \frac{\sqrt{L_r / C_r}}{n^2 R_L}$$

L

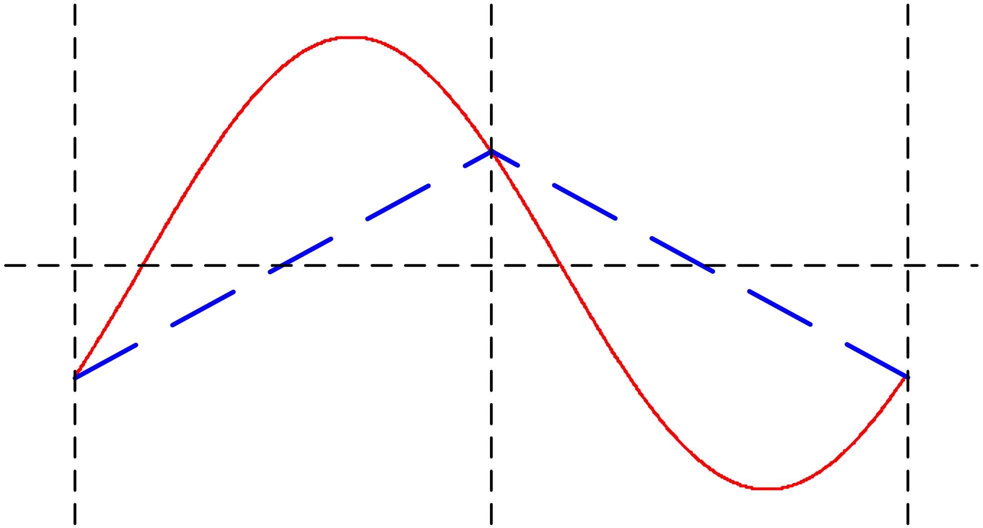
- Minimize RMS current under normal operation condition
- Ensure ZVS operation
- Ensure desired operation range

Choice of Lm

Criteria 1: Primary RMS Current at Normal Operation



$$I_{RMS\_P} = \frac{1}{4\sqrt{2}}\frac{V_O}{nR_L}\sqrt{\frac{n^4 R_L{}^2 T^2}{L_m{}^2} + 4\pi^2}$$



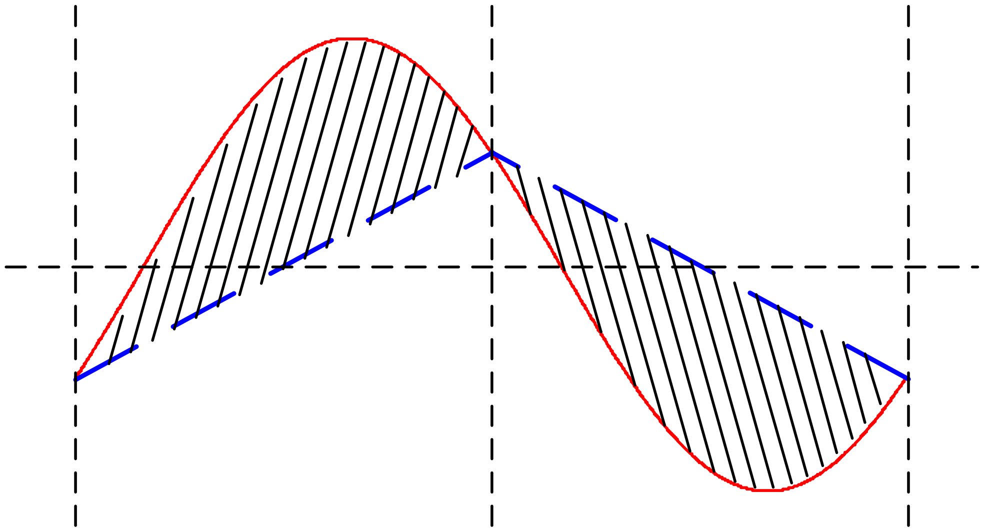
n:1:1

m

- Primary side RMS current is determined by magnetizing inductor
- Larger Lm the better

Choice of Lm

Criteria 2: Secondary RMS Current



Primary side current

$$I_{RMS\_S} = \frac{1}{4}\frac{V_O}{nR_L}\sqrt{\frac{5\pi^2-48}{12\pi^2}\frac{n^4R_L{}^2T^2}{\boxed{L_m{}^2}}+1}$$

- Secondary side current is the difference between resonant tank current and magnetizing current
- Larger Lm the better

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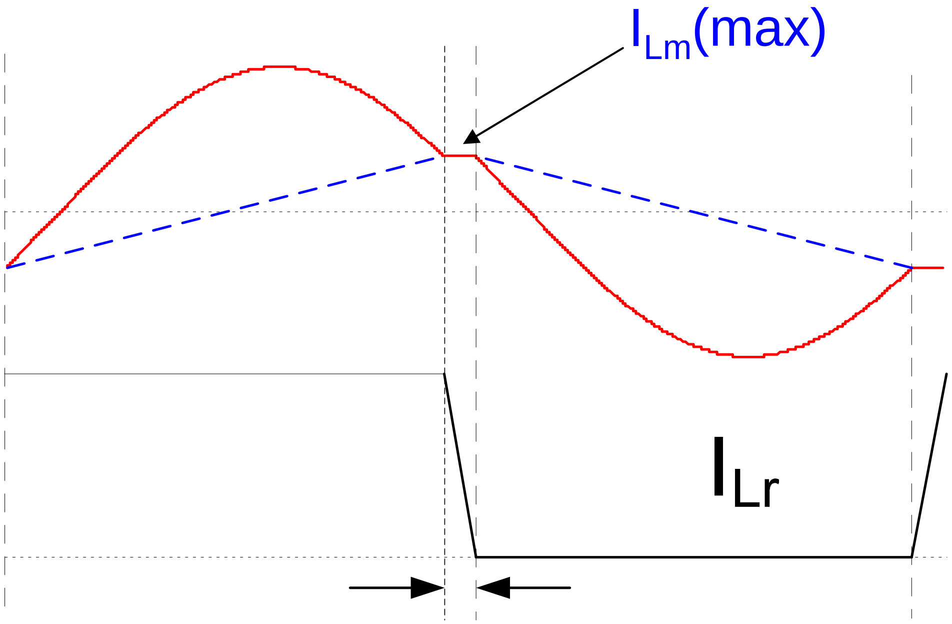
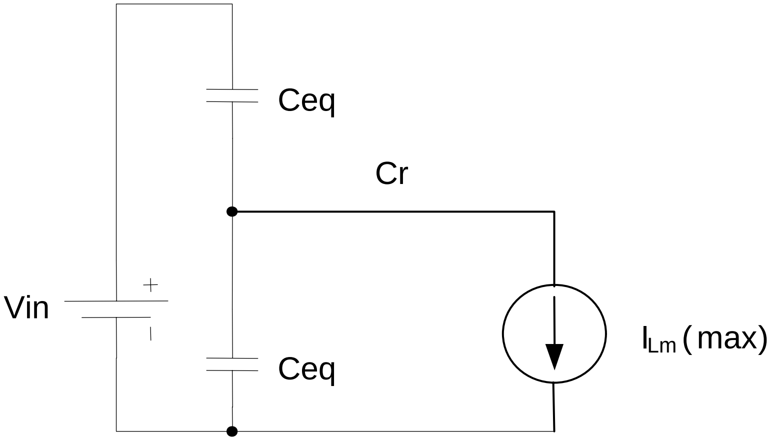
Choice of Lm

Criteria 3: Zero Voltage Switching





$$I_{Lm}(\max) = \frac{nV_o}{L_m}\frac{T}{4}$$

- ➢ Turn off current should be able to discharge junction caps during dead-time

$$L_m \le \frac{T \cdot t_{dead}}{16C_{eq}}$$

Trade-off Design of Dead Time

$t_{dead} \uparrow$

$L_m \uparrow$

- Smaller turn off current
- Smaller magnetizing current

- Increase RMS current due to duty cycle loss

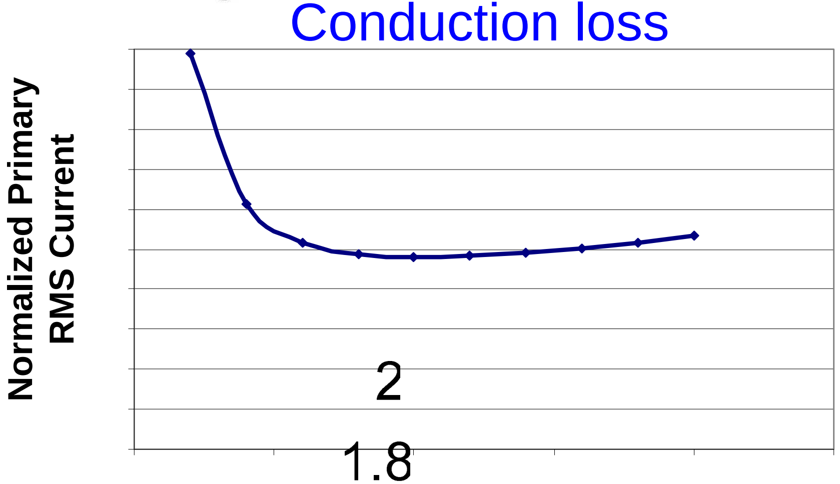
$t_{dead} \downarrow$

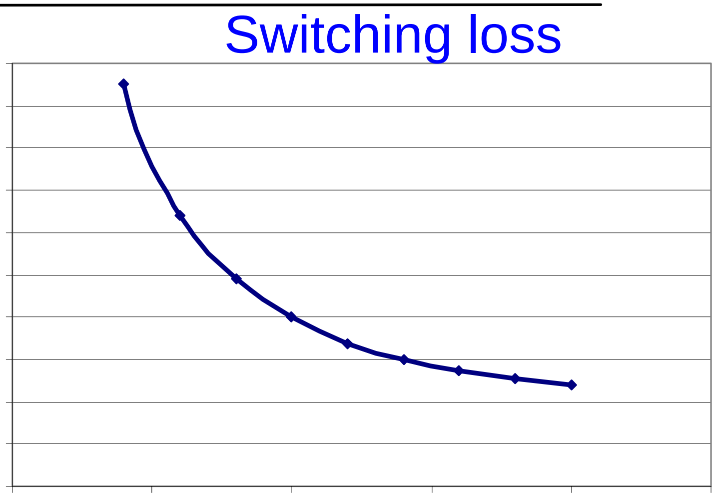
$L_m \downarrow$

- Smaller duty cycle loss

- Larger magnetizing current
- Larger turn off loss

Trade-off Design of Dead Time

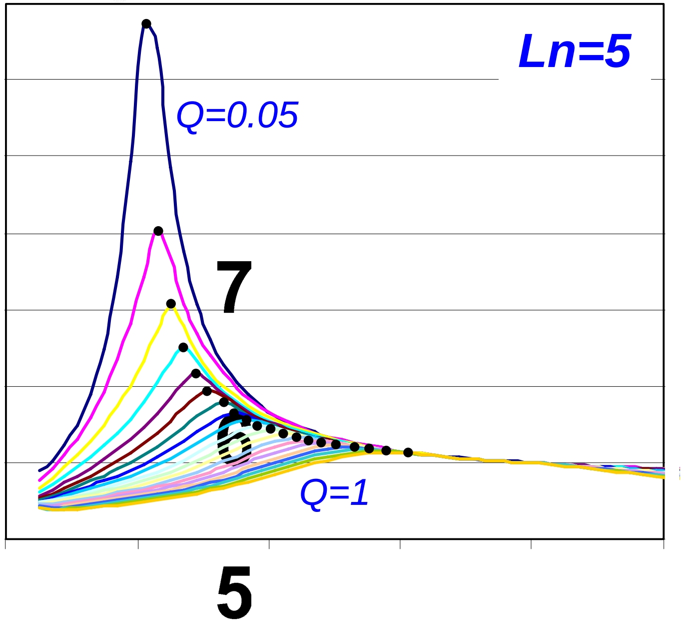

Conduction loss

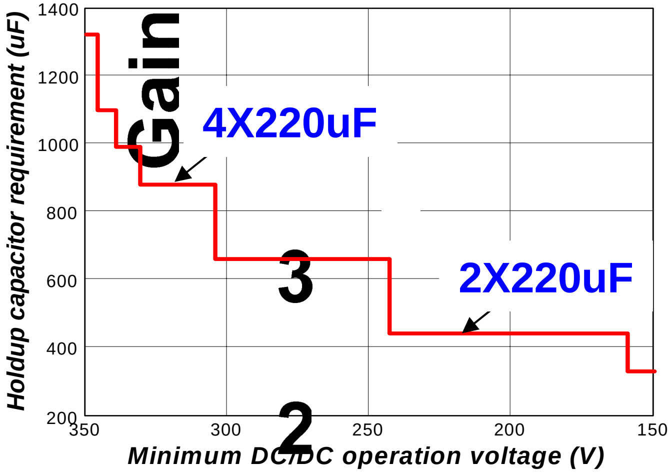

Switching loss

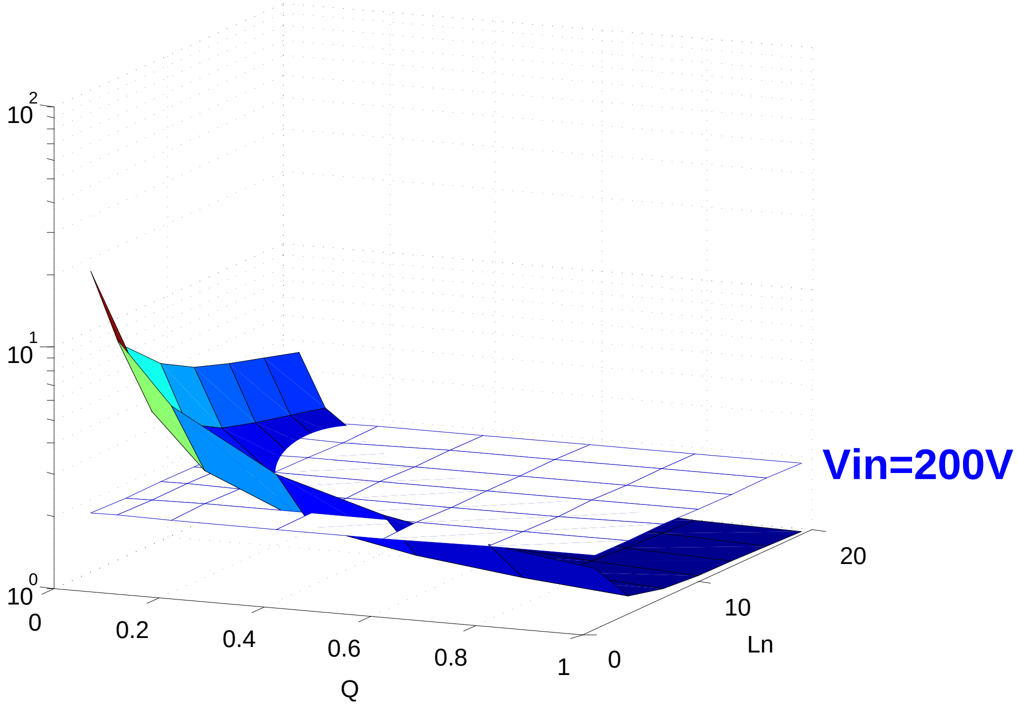

Total loss

- 100nS shows the trade-off between the switching loss and conduction loss

Achievable Peak Gain for Different Ln and Q







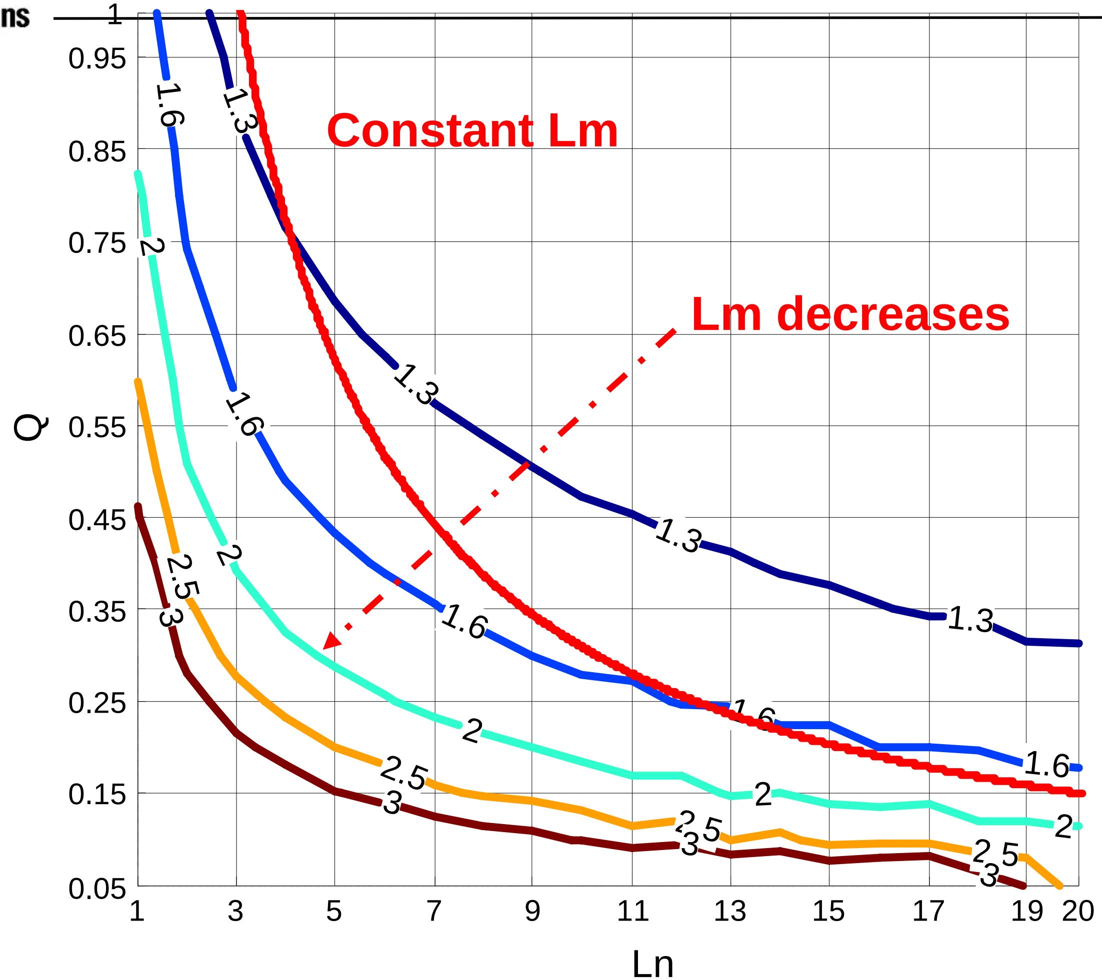
- **For each Ln and Q combination, the maximum gain can be achieved is determined**

- **Colored surface represent the maximum gain for different Ln and Q combinations**

- **Only certain Ln and Q region can meet gain requirement**

Gain

Peak Gains for Different Designs



$$\underbrace{Q=\frac{\sqrt{Lr/Cr}}{n^2R} \qquad L_n=\frac{L_m}{L_r}}$$

$$L_m = \frac{n^2R}{2\pi f_0}L_nQ$$

- ➢ To keep Lm constant and achieve low conduction loss and switching loss at normal operation, product of Ln and Q is expected to be constant
- ➢ Reduce Lm can help achieve higher peak gain

Start Up Current Consideration

$$Ip^* = \begin{cases} \dfrac{\pi^2}{4\cdot Q} & 1 < \Omega_S \le 2 \\ \dfrac{\pi^2}{4\cdot Q}\cdot\sin\left(\dfrac{\pi}{\Omega_S}\right) & \Omega_S > 2 \end{cases}$$

$$\Omega_S = \frac{f_{s-startup}}{f_0}$$

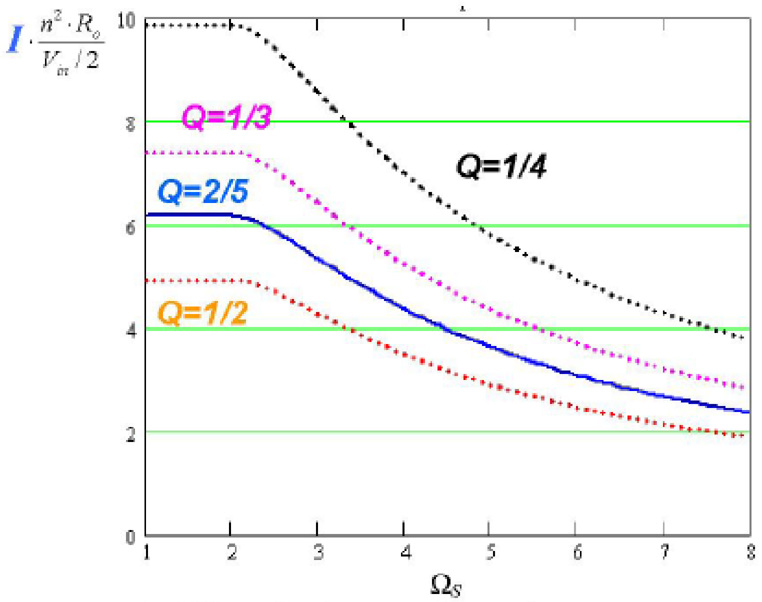
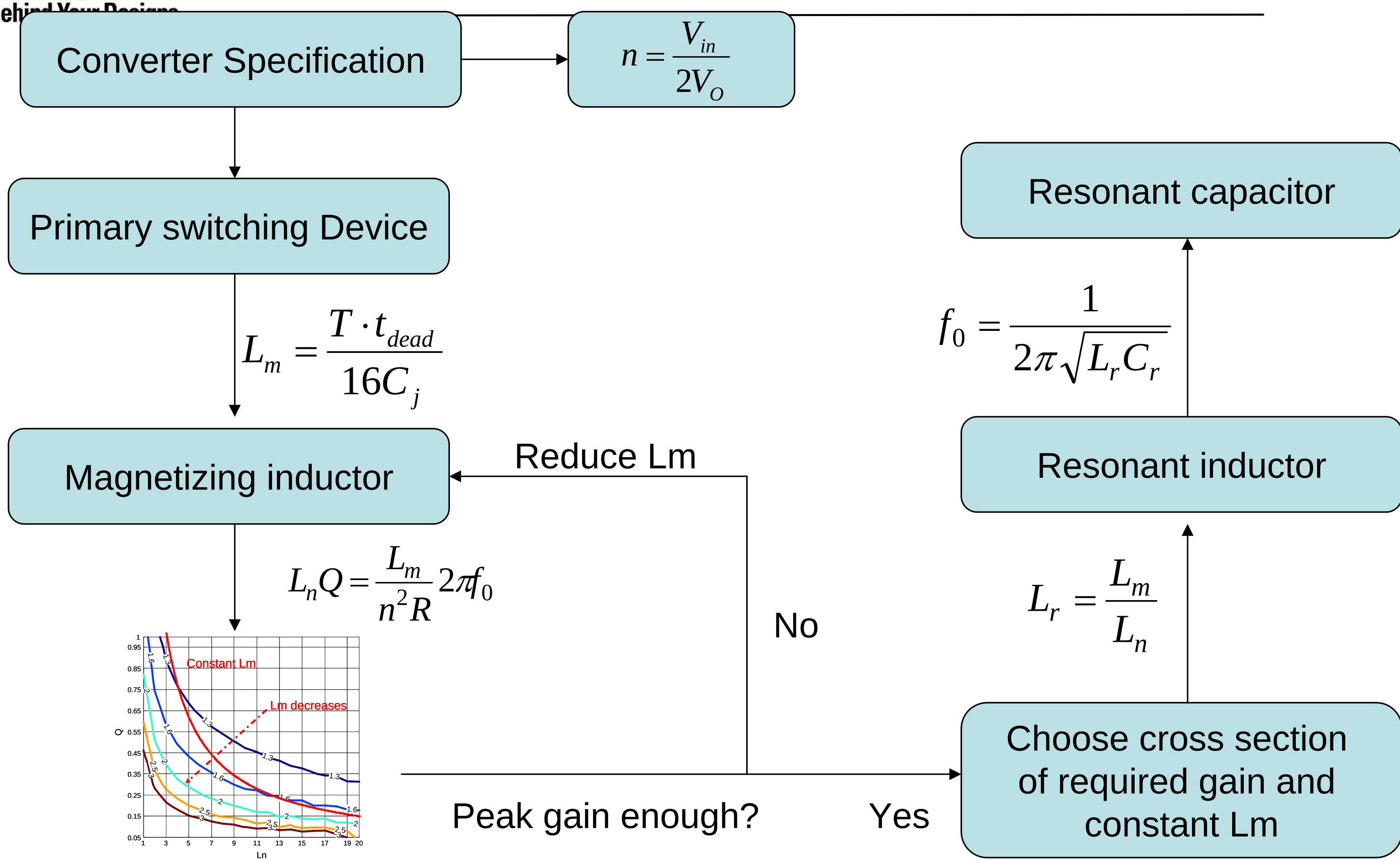


Fig.9 Normalized start-up first peak current

- Larger Q value gives smaller start up current with less frequency range

"A Novel Precise Design Method for LLC Series Resonant Converter", Teng liu, etc., INTELEC '06

Design Flow Chart for LLC Resonant Converter



Converter Specification

$$n = \frac{V_{in}}{2V_O}$$

Primary switching Device

$$L_m = \frac{T \cdot t_{dead}}{16C_j}$$

Magnetizing inductor

$$L_n Q = \frac{L_m}{n^2 R} 2\pi f_0$$

Peak gain enough?

No

Reduce Lm

Yes

Choose cross section of required gain and constant Lm

$$L_r = \frac{L_m}{L_n}$$

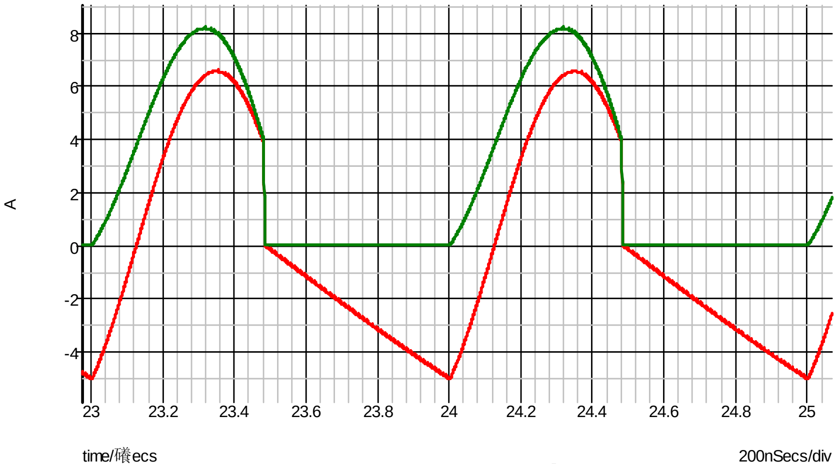
Resonant inductor

$$f_0 = \frac{1}{2\pi\sqrt{L_r C_r}}$$

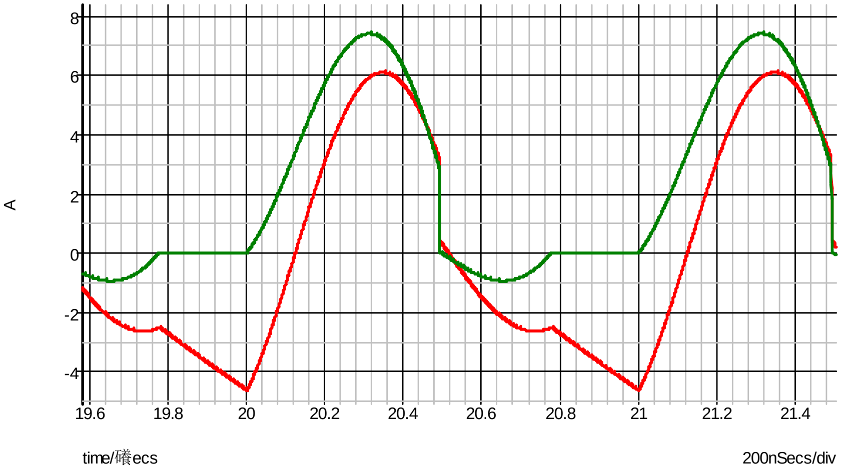
Resonant capacitor

Other Design Issues

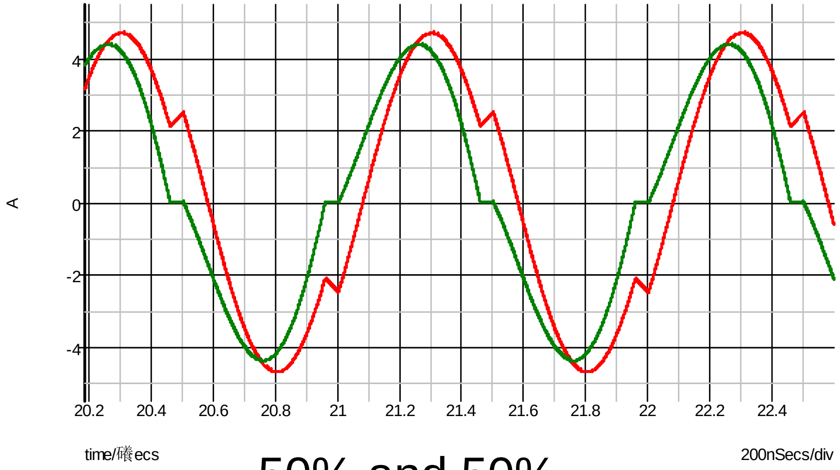
Asymmetrical LLC



48% and 52%



49% and 51%

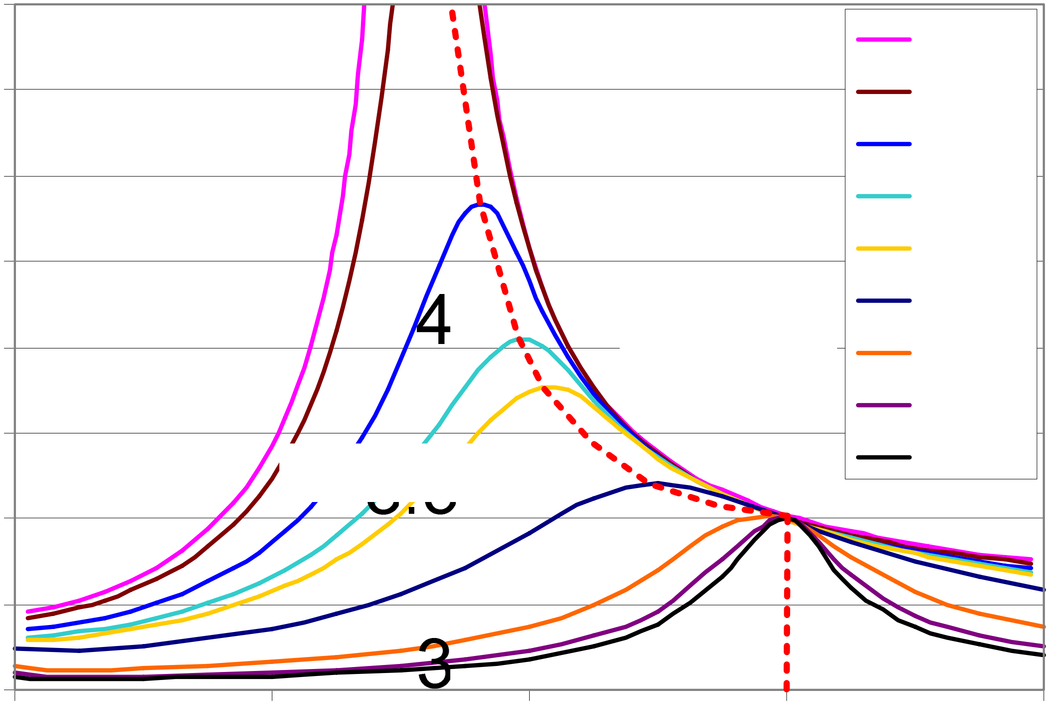


50% and 50%

- ➢Asymmetrical duty cycle makes resonant tank current unbalanced
- ➢Load current will be concentrated in one diode and increase conduction loss and switching loss
- ➢Controller should provide well matched PWM signal

Other Design Issues

Over Current Protection



$$Q=\frac{\sqrt{Lr/Cr}}{n^{2}R}$$

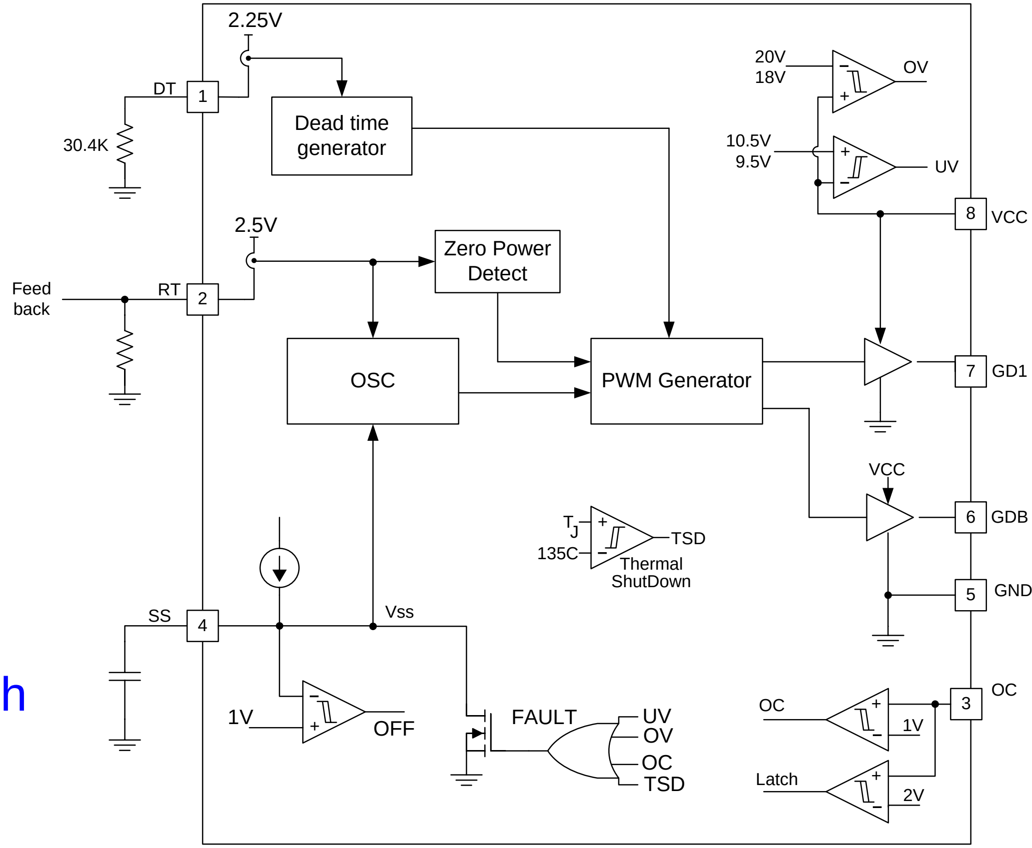
- At over load condition, switching frequency needs to be increased to maintain output current.

LLC Summary

- LLC resonant converter is able to achieve wide operation together with high efficiency
- Due to low switching loss, LLC resonant converter is able to operate high switching frequency, while maintain high efficiency
- LLC resonant converter design needs to find a suitable magnetizing inductor to ensure smaller conduction loss and switching loss
- By choosing a suitable Ln value, desired voltage gain can be achieved to reduce holdup time capacitor requirement

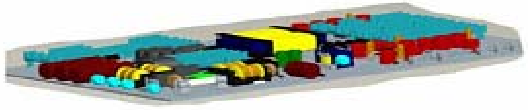
UCC25600 Key Features

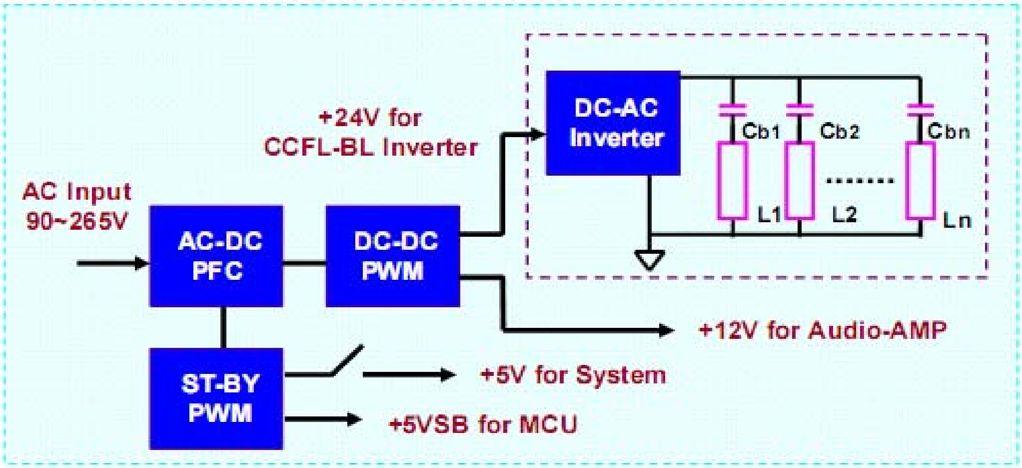
- ✓ 8 pin SOIC package simplifies circuit design
- ✓ Adjustable dead time allows optimal design for different applications
- ✓ Simple frequency control with minimum and maximum frequency limiting
- ✓ 3% min. frequency limiting reduces design margin
- ✓ Programmable soft start time with simple ON/OFF control
- ✓ Zero power shut down for light load regulation
- ✓ Two level over current protection with latch off
- ✓ Over temperature protection
- ✓ Gate driver capable directly drive half bridge with transformer

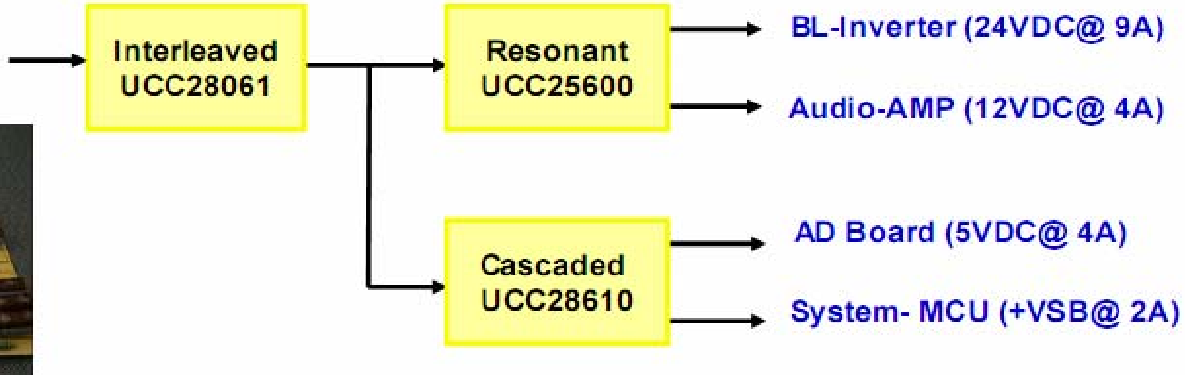


Slim 300W DTV design

Low Profile (15mm & 18mm)







Interleave transition mode PFC UCC28061

Features

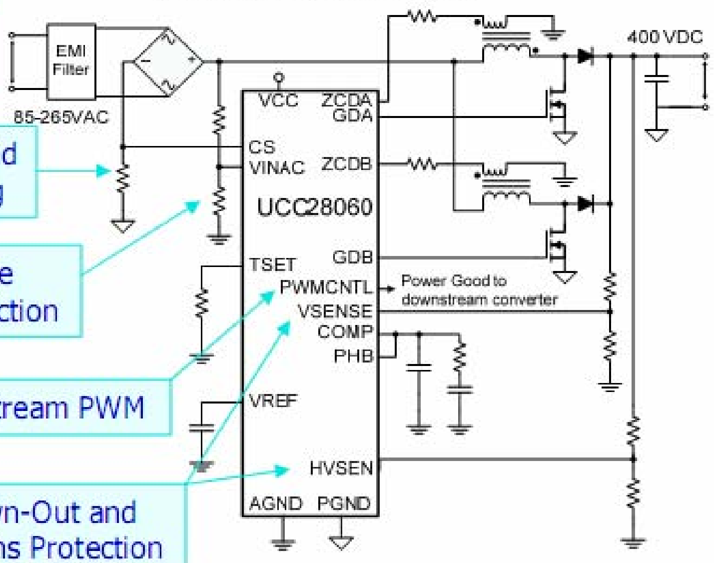
- Interleaved and Variable Frequency Operation for EMI Reduction
- Flexible Phase Management to Facilitate Energy Star Design
- Failsafe OVP with Dual Paths which Prevent any Voltage Loop Failure from Causing an Output Over Voltage Condition
- Senseless Current Shaping to Simplify Board Layout and Improve Efficiency
- In-rush Safe Current Limiting to Prevent MOSFET Conduction
- Slew Rate Comparator for Improved Transient Response

Applications

Selling Points

1. Low Profile Design with Distributed Components
2. Flexible Phase Management to Facilitate Energy Saving Design
3. Interleaved and Variable Frequency Operation for EMI Reduction
4. Lower System Cost (BOM) above 350W Power Design; Leading Technology

Typical Application



Over-Voltage and Open-Loop Protection

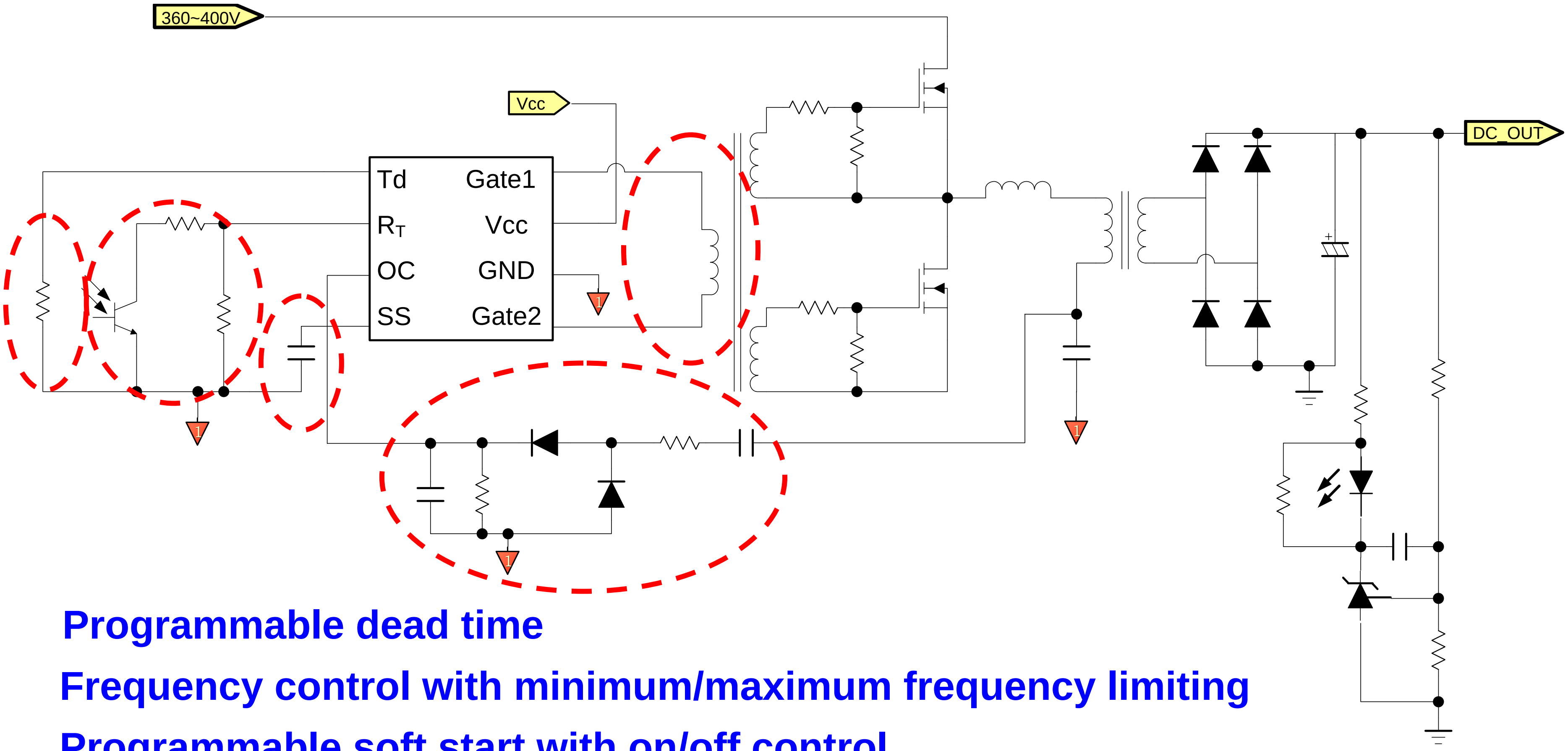
Senseless Current Shaping and In-rush Safe Current Limiting

AC I/P Voltage Brown-Out Protection

PG Signal to Downstream PWM

PFC O/P Voltage Brown-Out and Failsafe OVP with 2 Paths Protection

UCC25600 LLC controller Application Circuit



Programmable dead time

Frequency control with minimum/maximum frequency limiting

Programmable soft start with on/off control

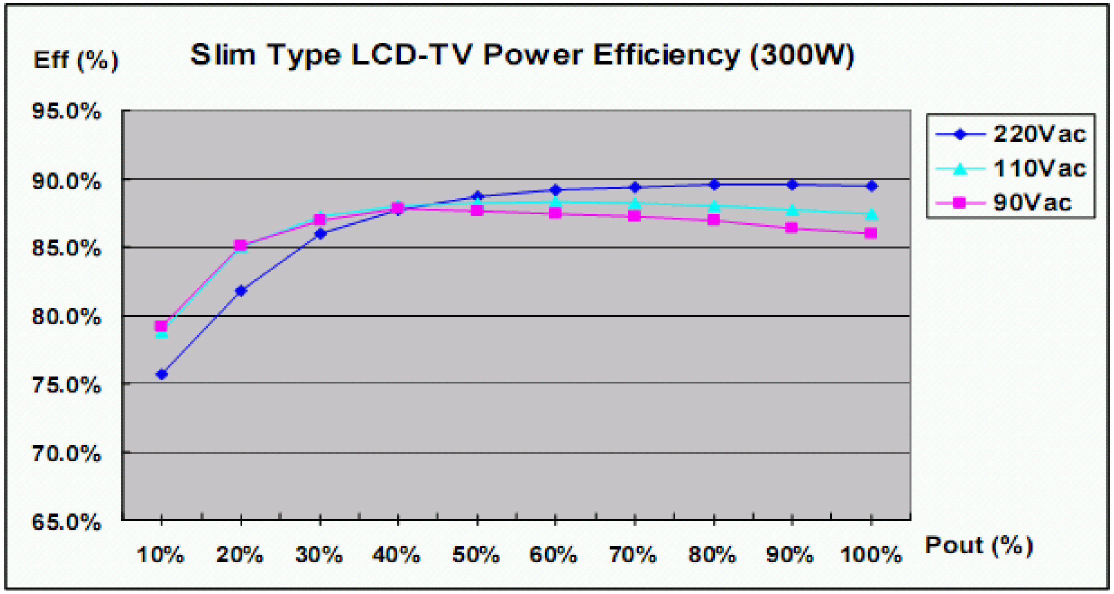
Two level over current protection, auto-recovery and latch up

Matching output with 50ns tolerance

Performance and BOM cost

➢ Efficiency & Thermal Evaluation

- 24V Rectifier is the Highest Temp. 82℃ at Room Ambit at 90VAC Input with Full-Load



➢ System BOM Cost Evaluation

- Conventional 300W LCD-TV Power Supply Unit (PSU) is about $14~15
- Slim-Type PSU Reference Design is estimated about $15~16 (5~10% Cost Incremental)

Summary

- TI 8 Pin Resonant Half Bridge Controller provides simple and reliable solution for resonant half bridge converter, including
  - 3% accurate switching frequency
  - Programmable max. & min. switching frequency
  - Programmable dead time
  - Soft start with easy ON/OFF control
  - Over current protection
  - VCC UVLO and over voltage protection
  - Integrated gate driver
- Provides system cost reduction through less external component and easy layout

Thank You

www.ti.com.cn